Biomechanical breast modeling to improve patient positioning during breast cancer radiotherapy

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1. Introduction

Accelerated partial breast irradiation (APBI) is being studied as an alternative to whole breast irradiation for cases of early stage breast cancer. Delivering higher doses to more localized volumes demands high accuracy guarantees in order to treat the target volume adequately and to spare healthy tissues and organs at risk.

An offset in the patient position compared to the position in the planning CT scan can lead to under dosed volumes increasing the risk of recurrences or can result in more lung or heart volume irradiated, increasing the risk of treatment complications. Accurately positioning the patient on the treatment table is therefore very important. This paper introduces the breast phantom that was developed to quantify the positioning accuracy during radiotherapy.

2. Methods

The aim of using a phantom was to be able to realize multiple acquisitions and to evaluate the accuracy of the positioning technique itself, without the interference of breathing and patient motion uncertainties. Maximum precision regarding patient setup on the treatment table must be the first priority study before focusing on other sources of uncertainty. Using a phantom the closest to clinical anatomical reality allows realizing multiple acquisitions of a perfectly similar anatomical breast throughout the treatment process, and evaluating the precision of the positioning on itself, without any other source of artefact.

Mechanical properties of the breast phantom and choice for the breast/bust connection type

We decided to build a phantom with a 600 cm^3 deformable breast fixed onto a polystyrene bust. This volume was assumed to represent a reasonable size for a breast, *i.e.* large enough to expect breast deformations within the order of one centimeter when the phantom is placed on the side. Larger volumes with corresponding higher deformations will be studied in the future. Two questions were then raised as concerns the design of this phantom: (1) Assuming that the breast tissues are made of a thin layer of stiff epidermis/dermis tissues (the skin) enveloping softer subcutaneous and glandular tissues, what mechanical properties should be provided to the corresponding materials in the breast phantom and what would be the optimal skin thickness? (2) How should the breast phantom be fixed to the polystyrene bust?

In order to answer to these questions, we developed a virtual model of the phantom defined by a Finite Element breast model. Responses to question (1) should be provided by tuning the skin thickness and the elastic parameters of the elements that model the epidermis, dermis, subcutaneous and glandular tissues. Question (2) should be solved by modifying the boundary conditions that describe the attachment of the breast model onto the rigid bust.

The breast morphology (left breast) was recorded using an optical localizer (Polaris from NDI Inc.) and a digitizer. The breast volume was then meshed using a hexahedron-dominant mesh generator (Lobos *et al.*, 2010), able to distinguish surface elements (that represent epidermis and dermis tissues) and elements inside the volume associated to subcutaneous and glandular tissues.

3. Results and Discussion

A coherent global deformation of the breast under gravity was observed with the corresponding mechanical parameters, thus responding to question (1): a 0.5mm skin thickness with a Young modulus (i.e. stiffness) for breast subcutaneous and glandular tissues around 20 kPa (Krouskop *et al.*, 1998) while the tissues enclosed in the skin envelope (epidermis and dermis) get a 100 kPa value for the Young modulus (Liang & Boppart, 2010; Diridollou *et al.*, 2001). Finally, since human tissues can be considered as quasi-incompressible as they are mainly composed of water (Fung, 1993), a 0.49 value was chosen for the Poisson Ratio of the material. To provide a response to question (2), we had to look at the connection between the breast and the thorax. Anatomically, subcutaneous and glandular tissues composing a human breast are not tightly connected with the surrounding skin, allowing these tissues to spread underneath the skin surface. This phenomenon is a major reason for such high deformability and motion of breast with position changes. To try to fit as close as possible to

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this reality, two boundary conditions (i.e. the connections between the breast and the underlying thorax) were implemented and tested with the Finite Element model: a full adhesion and a central band thorax adhesion between the breast phantom and the polystyrene bust.
Figure 1 shows the breast model deformations facing a 45° inclination gravity load for two different skin thicknesses (top panels) and with a partial (lower left panel) and a full (lower right panel) adhesion.

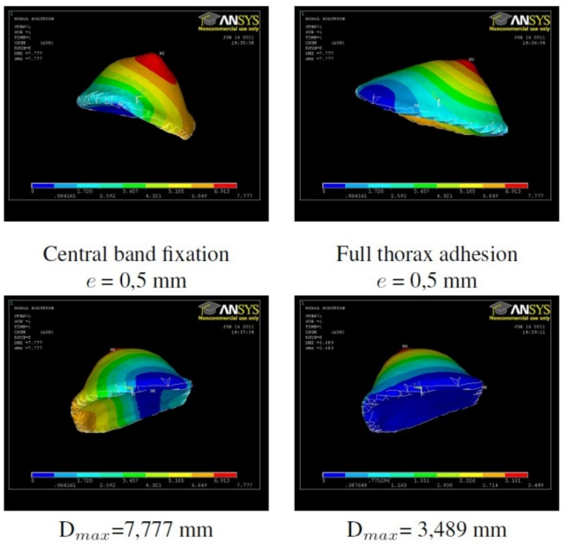

Figure 1: Displacements of the breast Finite Element model facing a 45 degrees gravity load, with different skin thicknesses (top panels: 0.5mm and 2mm) and with two boundary conditions for thorax adhesion (low panels: central band (left) and full adhesion (right)).

The central band thorax adhesion and a 0.5mm thickness for the skin seem to provide the most realistic behavior of the breast model since a displacement close to 8mm was observed in that case, qualitatively corresponding to what is observed in practice. It was therefore decided to use such thickness and boundary conditions in the physical design of the breast/chest phantom.

Breast phantom construction

A silicon RTV-EC00 material was chosen to represent the epidermis/dermis (material #1) and the subcutaneous/glandular tissues (material #2). By varying the concentration in base or catalyst making the silicon, the global stiffness of the materials was impacted. An aspiration device (Schiavone et al., 2010) was used to determine the adequate concentrations for both materials in order to get the values provided with the finite element model (i.e. 100kPa for material #1 and 20kPa for material #2). Figure 2 plots the corresponding breast phantom. A central band (part of which can be seen in black on that figure) was used to fix the breast phantom onto the polystyrene bust.

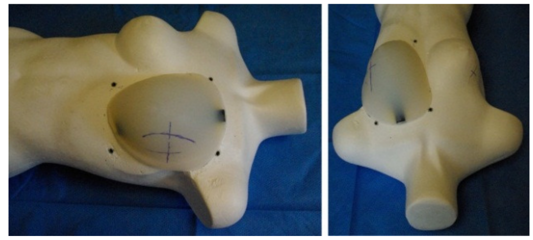

Figure 2: Breast phantom (silicon material) fixed onto a polystyrene bust with a central band

4. Conclusion

This dedicated phantom has been recently used to quantify the positioning accuracy during radiotherapy. In particular the influence of breast deformations onto the precision of the isocenter position is studied. For this, the phantom is positioned on the treatment table several times using skin marks laser alignment with the same standard contention system as for the planning CT scan. As a perspective, the Finite Element model might be used to assist the clinician in order to predict (and to compensate) breast deformations as discussed in Han *et al.*, 2012.

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